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Cally Driessen
University of Wyoming Department of Renewable Resources

Amber Mason
University of Wyoming Department of Renewable Resources

Jay Norton
University of Wyoming Department of Renewable Resources

Calvin Strom
Wyoming Reclamation and Restoration Center

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Cally Driessen, Amber Mason, and **Jay Norton** University of Wyoming Department of Renewable Resources, Laramie, Wyoming and **Calvin Strom** Wyoming Reclamation and Restoration Center, Laramie, Wyoming

ABSTRACT

Wyoming shrublands have undergone extensive energy development in recent years. Much of this development occurs on public land designated for multiple uses. Reclamation of these areas has proven difficult due to the harsh climate and alteration of the thin, nutrient poor topsoil during development activities. Energy development and reclamation activities often lead to topsoil dilution, rapid mineralization of nutrients and soil organic matter (SOM), and loss of soil structure. These changes have the potential to degrade the suitability of the soil as a medium to sustain a desirable plant community. Reclamation of land disturbed for energy development in this area has largely been executed by the extraction companies and evaluated by the governing agency (typically, the Bureau of Land Management (BLM)). Other parties who rely on this land, such as ranchers with grazing permits, are not typically involved in reclamation. In this study, we examine an unconventional reclamation technique that aims to involve ranchers in the reclamation process: controlled livestock impact. The theory behind this technique is that by confining livestock on a seeded and reclaimed site the animals will improve the seedbed and seed to soil contact through fertilization and hoof action. Natural gas well pads that were reclaimed in the fall of 2009 were selected from three Wyoming natural gas fields. Two treatment plots were established on each well pad: traditionally reclaimed and reclaimed with the cattle impact treatment. Cattle treatments were applied in fall 2009 immediately after reclamation and seeding. Soil samples were taken from the reclaimed plots and before and after the cattle impact on treated plots. Soil samples were then analyzed for SOM parameters including percent light fraction organic matter (LF) and labile C and N. Post-cattle treatment plots had more mineralizable C and more N variability than pre-cattle plots, which indicates an impact from the cattle treatment on SOM characteristics.

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INTRODUCTION

Natural Gas Well Pad Reclamation in Wyoming

Wyoming is one of the nations' leaders in natural gas production and proven reserves. The Energy Information Administration reports that Wyoming ranks second in the United States for proven dry natural gas reserves as of 2008 (USEIA 2009). Natural gas development in Wyoming occurs on state, federal, and private land, which is often used for livestock grazing, wildlife habitat, recreation, and other activities in addition to resource extraction. Natural gas extraction in Southwest Wyoming requires a level area for drilling activities (well pad), pipelines for transport of resources, and access roads for maintenance. The nature of this type of land disturbance has resulted in habitat loss or fragmentation (Walston and others 2009), wildlife avoidance (Lyon and Anderson 2003; Sawyer and others 2009), changes in plant communities (Bergquist and others 2007), and other indirect consequences. Thus, techniques that accelerate the successful reclamation of these sites are highly desirable.

Reclamation of Wyoming's shrublands is often difficult because of harsh climate, nutrient poor topsoil, changes in soil properties during development and reclamation activities, herbivory, and lack of viable seed. Many mechanisms have been explored to ameliorate these issues, but are often expensive or difficult to implement. Furthermore, other affected parties, such as ranchers, are rarely incorporated into reclamation plans although their livelihoods may depend on successful reclamation.

Controlled Livestock Impact

Controlled livestock impact has gained popularity with land managers in recent years as a reclamation tool. A large collection of testimonial evidence exists proclaiming the success of using animals to prepare the seedbed and maintain a desirable plant community, but little science-based research has assessed these claims. Controlled livestock impact is different from grazing, as it is a treatment applied to a site with little to no standing forage. Grazing or browsing animals are confined at high density on a reclaimed area and are fed, and often allowed to bed down, on the location. The idea behind this is that the combination of hoof action and addition of organic materials will improve soil conditions for plant establishment. Seeding may occur before or after the livestock impact treatment, or mature native grass hay may be used to both feed the livestock and provide seed to the area.

This study aims to quantify the immediate effects of a controlled livestock impact on basic soil organic matter (SOM) characteristics. SOM is important for plant establishment on reclaimed locations as it provides nutrients, improves water holding capacity of soils, and reduces erosion by promoting aggregation of soil particles. Moreover, reclaimed soils in Wyoming have been shown to have lower SOM than comparable undisturbed soils (Anderson and others 2008; Ingram and others 2005; Mummey and Stahl 2004; Stahl and others 2002;, Wick and others 2009a; Wick and others 2009b). This study was designed to assess the immediate effects of controlled livestock impact on SOM, thus we focused our efforts on characterizing the labile organic matter pools. Labile and light fraction (LF) organic matter pools reflect changes in topsoil management and are good indicators of topsoil quality (Sohi and others 2010). We expect that both the labile organic C and N pools will be higher after the cattle treatment than before. We believe that contributions of waste feed and excrement will increase the amount of C and N in the labile organic pool. Furthermore, we hypothesize that there will be more LF after livestock treatment for similar reasons.

METHODS

Study Area

Ten well pads were selected from three Wyoming natural gas fields: Pinedale Anticline (Anticline), Jonah, and Wamsutter. The pre-disturbance ecological site descriptions for the Anticline well pads are loamy or shallow loamy 10 to 14-inch Foothills and Basins and clayey or gravelly 7 to 9-inch Green River and Great Divide; and either clayey or loamy 7 to 9-inch Green River and Great Divide for the Jonah. (NRCS 2009). The NRCS has not yet classified the ecological sites for the Wamsutter area, but we found the soil to have sandy loam texture and the dominant vegetation is Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) or Gardener's saltbush (*Atriplex gardnerii*). All of the fields are cool and dry with the majority of the annual precipitation occurring as snowfall (table 1).

Sampling Design

Each well pad was assigned two treatment plots on the reclaimed area, one of which received the controlled livestock impact treatment (cattle) and one which did not (reclaimed). The cattle plots were sampled before (pre-cattle) and after (post-cattle) the livestock treatment was implemented. Plots were 0.10 ha (0.25 ac) in size with three, 34 m (112 ft) permanent transects. Soil samples were taken at 0 to 5-cm (0 to 2.5-inch) depth at three locations along transects and bulked by transect.

Table 1. Climate information for the three natural gas fields. Data obtained from Western Regional Climate Center from nearest data loggers to each gas field based on averages from 1948 to 2005.

Site	Average Max Temp *°C (°F)*	Average Min Temp *°C (°F)*	Mean Annual Precip *mm (in)*
Anticline	10.9 (51.7)	-6.72 (19.9)	277 (10.9)
Jonah	12.7 (54.8)	-6.50 (20.3)	187 (7.35)
Wamsutter	12.9 (55.3)	-2.61 (27.3)	174 (6.84)

Controlled Livestock Impact Treatment

The well pads were reclaimed and seeded in the fall of 2009. Topsoil handling and storage, seed mixes and seeding rates, and mulching varied between natural gas fields due to differences in company policies and governing legislation. The cattle treatment was superimposed on the traditional reclamation and seeding for each field. Cattle plots were temporarily fenced and certified weed-free hay was scattered throughout the fenced area. On the Jonah and Anticline production areas, 25 cows occupied the 0.10 ha (0.25 ac) plots for 24 hrs; while 12 bulls occupied the Wamsutter area plots for 48 hrs. This stocking rate was determined by estimating the amount of organic matter lost through construction and reclamation activities and then calculating how much organic material; in the form of feces, urine, and excess feed; a single cow contributes in a day. According to the Natural Resources Conservation Service (NRCS), a typical 453.6 kg (1000 lb) beef cow produces 4.85 kg (10.7 lb) of manure per day (NRCS 2010), which yields 1.13 kg (2.5 lbs) of dry organic material per 453.6 kg animal per day (van Vliet and others 2007). Also, cattle typically waste about 30 percent of total hay fed on the ground, or as much as 8.16 kg (18 lbs) per animal per day for low-quality forage. Data from reclaimed coalmines suggest that 35 to 69 percent of SOM is lost by the time the soil is reclaimed (Anderson and others 2008; Ingram and others 2005; Mummey and Stahl 2004; Wick and others 2009a; Wick and others 2009b). Assuming a bulk density of 1.3 g cm^{-1} and an initial SOM content of 1.5 percent, 183 to 362 cattle ha^{-1} d^{-1} (74 to 147 cattle ac^{-1} d^{-1}) would be required to replace the organic matter loss. We adjusted our final stocking rate of 240 cattle ha^{-1} d^{-1} (100 cattle ac^{-1} d^{-1}) after discussing feasible rates with the cattle producers who cooperated with this project.

Laboratory Analyses

Soil samples were immediately chilled at 4 °C upon collection until they reached the laboratory. Soil was then divided for field-moist analyses and dry analyses. Field moist samples were used for assessing labile organic pools. Dry samples were dried at room temperature for 48 h, and then sieved to 6.35 mm (0.25 inch) for LF analysis.

Labile Organic C and N

Approximately 10 g of field moist samples were immediately extracted with 50 mL of K_2SO_4 using Q5 filters, upon returning to the lab. This analysis allows quantification of bio-available N that is immediately available in the soil, which is also known as mineral N. Another 10 g was used to determine gravimetric moisture content (Gardner 1986) so samples could be normalized for moisture content. Extracts were frozen for storage and then run on a microplate spectrophotometer (Powerwave HT, BioTek Instruments, Vinooski, Vermont) for NH_4-N and NO_3-N as described by Larios (2008). For NH_4, 40 mL of sample was mixed with 80 mL of sodium salicylate solution and 80 mL of bleach-NaOH solution and allowed to develop color for 1 hr before reading on the spectrophotometer. NO_3 analysis used 10 mL of sample to 190 mL of VCl_3-HCl solution (Doane and Horwath 2003) and was developed for 18 hr before reading.

Twenty-two g of field moist soil was brought to approximately 23-percent moisture content for labile C and N. Soil underwent a 14-day aerobic incubation as described in Zibilske (1994) and Hart and others (1994). Carbon dioxide samples were drawn out using 30-ml syringes through the rubber septa in the incubation jars on the first, fourth, seventh, eleventh, and last days of the incubation period. These samples were then analyzed on an infrared gas CO_2 analyzer (LI-820, LI-COR Inc, Lincoln, Nebraska) on the days they were withdrawn. A 10-g sub-sample of the 22 g sample was analyzed for gravimetric moisture at the end of the 14-day incubation period to correct for actual moisture content. The cumulative C released over the 14-day incubation period is the potentially mineralizable C, or labile organic C content of the soil.

After the 14-day incubation period, the remaining soil was extracted with 50 mL of K_2SO_4. The sample was analyzed for NH_4 and NO_3 as described for mineral N above. This represents the amount of organic N mineralized under optimal conditions after a 14-day incubation period. Potentially mineralizable N or labile organic N is achieved by subtracting the initial inorganic N content from the N content after the 14-day incubation period.

LF

A 10-g sample from the dried and sieved soil was used for organic fraction analysis. The density fractionation method described by Sohi and others (2001), using 1.8 g cm^{-1} NaI, was used to obtain LF. Free LF (fLF) was collected from the surface of the solution after gentle mixing, while occluded LF (oLF) was collected after vigorous shaking and 110 seconds in a sonicator. Both forms of LF were centrifuged at 2000 rpm until mineral components of the sample settled to the bottom of the tube. Lids and rims of tubes were rinsed with more NaI and LF was collected using an aspirator. Samples were collected on a nylon 20-mm filter and rinsed thoroughly with deionized water. Samples were then dried in aluminum tins at 60 °C (140 °F), and weighed to 0.0001 g. These two fractions determined by density represent total LF (von Lutzow and others 2007).

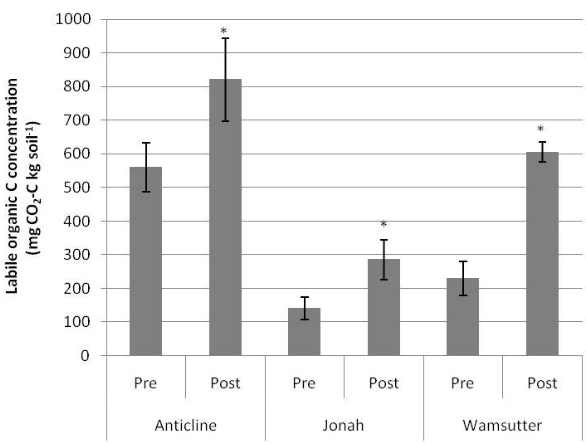

Figure 1. Labile organic carbon (cumulative mg CO_2-C kg $soil^{-1}$ during 14-d incubation) from pre-cattle and post-cattle sampling for the three natural gas fields. Error bars represent standard error. *significantly ($p < 0.05$) higher labile organic carbon between treatments within a natural gas field.

RESULTS

Paired t-tests were used to determine differences between the pre and post-cattle treatments. Statistical tests were based on treatment means and an alpha of 0.05 was used to determine significance.

Labile Organic C and N

Labile organic C concentrations were significantly higher after the cattle treatment for the Anticline ($p = 0.027$), Jonah ($p = 0.006$), and Wamsutter ($p = 0.010$). There were also noticeable differences in labile organic C between the sites, with the highest on the Anticline, followed by Wamsutter, and finally, the Jonah (figure 1).

While differences between natural gas fields existed, there was no difference in mineral N after the cattle treatment within a location (figure 2a). Labile organic N was greater before the cattle treatment for the Jonah ($p = 0.003$) and no trends are observed between natural gas fields. The data for both the Anticline and Wamsutter do, however, suggest that there is increased variability in labile organic N after the cattle treatment (figure 2b).

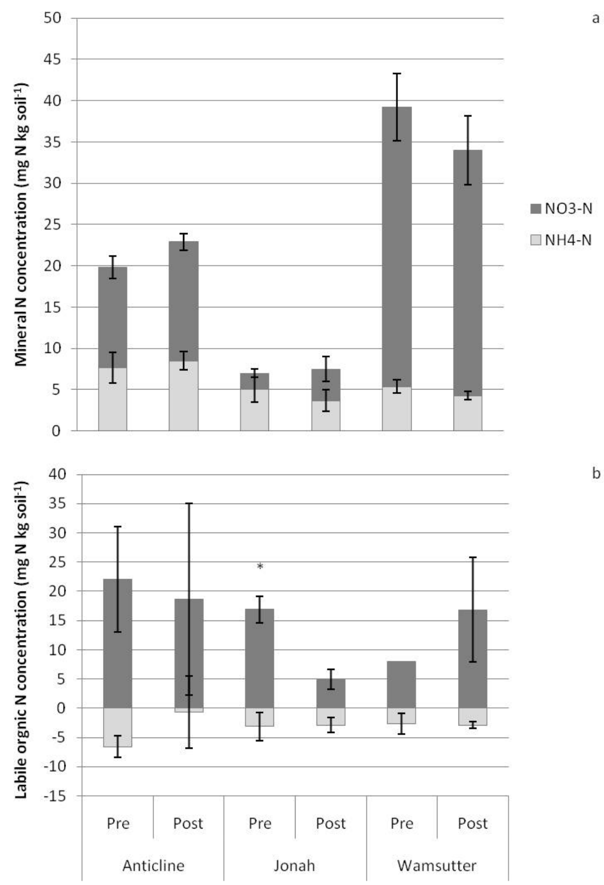

Figure 2. Mineral (a) and labile organic (b) N concentration (mg N kg $soil^{-1}$) in the forms of NO_3^- and NH_4^+ for three natural gas fields before and after cattle treatment. Mineral N is the initial concentration of available N while labile organic N is the initial mineral N subtracted from mineral N after a 14 d aerobic incubation period. Negative NH_4^+ values suggest nitrification occurred during the incubation period. Error bars denote standard error. *significantly ($p < 0.05$) higher N concentration between treatments within a natural gas field.

LF

There was no difference in fLF after the cattle treatment on any of the gas fields. Differences between gas fields are similar to those seen in the labile organic pool, with Wamsutter the highest, then the Anticline, and Jonah the lowest (figure 3a).

There was significantly higher oLF after the cattle treatment on the Jonah ($p = 0.006$), but not on the other two fields. Differences between fields follow the same trend seen in the other organic matter characteristics (figure 3b).

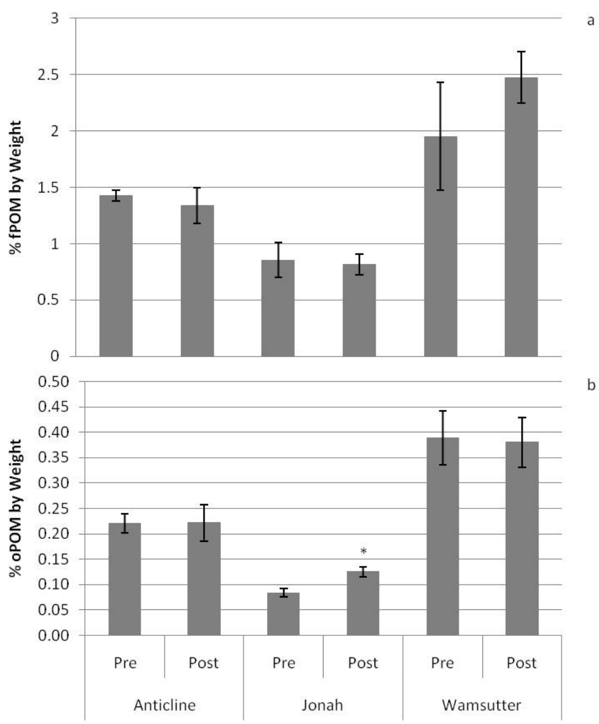

Figure 3. Free (a) and occluded (b) light fraction organic matter percent by weight before and after cattle treatment for three natural gas fields. Error bars indicate standard error. * significantly ($p < 0.05$) higher percent light fraction organic matter after treatment within a natural gas field.

DISCUSSION

Labile Organic C and N

As hypothesized, labile organic C content was higher post-cattle than pre-cattle. These results are similar to those of agricultural plots in a shrub-steppe ecosystem treated with composted dairy waste (Cochran and others 2007). In this agricultural study, a 175-day incubation period revealed cultivated soils treated with dairy compost mineralized more C than untreated plots with native vegetation (Cochran and others 2007). Another agricultural study found that plots treated with additions of sewage sludge compost, dairy manure compost, and corn silage compost had higher total C and available C than untreated or conventionally fertilized plots (Lynch and others 2005).

Contrary to labile organic C pools, N pools did not agree with the hypothesis that N would be higher after the cattle treatment. This relationship yields a higher C: N in the labile pool, which is more similar to what is expected on native rangeland. One possible explanation for this is that N could have been immobilized or volatilized immediately after the treatment was applied. Burgos and others (2006) found this phenomenon to be true in sandy soils for two organic amendments. They observed that municipal sewage compost and agro-forest compost both initially immobilized N and then continuously released mineral N for the duration of the study (Burgos and others 2006). Continued sampling may reveal whether the cattle treatment amendment behaves similarly to other soil organic amendments. Labile organic N on the Anticline and Wamsutter fields may lack differences between treatments due to the high variability on the post-cattle plots. On the other hand, this variability may imply that the cattle treatment promotes heterogeneous soil conditions; which could be important for reinstating the patchiness of soil quality that naturally occurs on Wyoming shrublands (Burke 1989; Eviner and Hawkes 2008).

LF

No differences were observed between the pre and post-cattle data for fLF or oLF. The one exception was the occluded fraction on the Jonah where, as hypothesized, the oLF fraction was higher after the cattle treatment. Wick and others (2009a) found the highest amount of microaggregates, 53 to 250 mm (0.002 to 0.010 inch), during the first year of reclamation. In spite of this fact, the first year after reclamation had the lowest amount of interaggregate LF C (Wick and others 2009a). The Jonah site could have more oLF after the cattle treatment because the organic additions may have been trapped during the formation of these first-year aggregates. Furthermore, the Jonah post-cattle treatment was the only location to have significantly less labile organic N than before the cattle treatment. This may suggest that some of the labile N was not only immobilized by microbes, but also fixed in soil aggregates. Additional analyses on C and N content of the fLF and oLF fractions would provide more insight to the processes occurring on the treated plots.

CONCLUSIONS

In conclusion, the controlled livestock impact explored in this study had immediate effects on soil labile C and N and on LF pools. Whether or not these effects translate to achieving short-term reclamation goals remains to be seen. Soil and vegetation parameters will be continually monitored during the 2010 growing season. Results from these and further analyses of the 2009 samples may reveal more of the impacts this cattle treatment has on SOM properties.

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